National Aeronautics and Space Administration

Radiation Budget Instrument

RBI Instrument Overview

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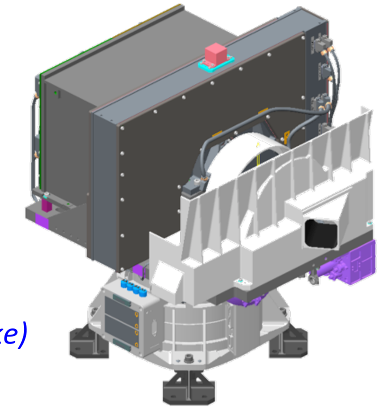
Radiation Budget Instrument (RBI)

Partnerships and Teams

- **NASA/ NOAA Partnership**
  - NOAA provides JPSS-2 satellite for accommodation of RBI
  - NASA provides RBI instrument and support through spacecraft I&T and launch/activation
  - NASA funds radiation budget science data analysis and generation of science products (RBM Project)
- **NASA Langley**
  - Manages prime contractor development of RBI instrument, provides management, technical, and mission assurance insight and oversight; provides support to spacecraft I&T thru launch and early on-orbit checkout (thru Phase D)
  - Hand-over and release of RBI instrument ownership by RBI Project occurs at the JPSS-2 Operational Hand-over Review (OHR). For Phase E, the Langley Science Directorate (SD) Radiation Budget Measurement (RBM) Project assumes responsibility for RBI for mission planning and operations
- **Harris Corp.**
  - RBI Instrument provider/prime contractor with sub-contractors providing key elements and support (SDL for Calibration, JPL for Thermopile Detectors, Sierra Nevada for Azimuth Rotation Module)
- **JPSS-2 Spacecraft and Mission Interface**
  - -- Interface Control (ICD & MICD) and Data Format

RBI scanning radiometer measuring three spectral bands at top of Atmosphere (TOA)

- Total 0.3 to > 50+ μm
- Shortwave 0.3 to 5.0 μm
- Longwave 5.0 to 50+ μm *(FM-6 like)*



Science Goal

- To ***continue*** the measurements from the last two decades in support of global climate monitoring.
- RBI ***extends*** the Earth radiation budget measurements of the Earth Observing System (EOS) and Joint Polar Satellite System (JPSS)

- **Phase:** Formulation (C)
- **Risk:** 7120.5E, Category 2; 8705.4 Payload Risk Class B
- **Flight Instrument Delivery:** March 2019
- **JPPS-2 On-dock Delivery Date:** April 2019
- **Life:** 7 years

RBI is a CERES Data Continuity Mission

Partnerships and Teams

HARRIS

NASA

Space Dynamics LABORATORY
Utah State University Research Foundation

Jet Propulsion Laboratory
California Institute of Technology

L-1

SNC SIERRA NEVADA CORPORATION
Space Systems
A WORLD CLASS LEADER IN SPACE SYSTEMS & TECHNOLOGIES

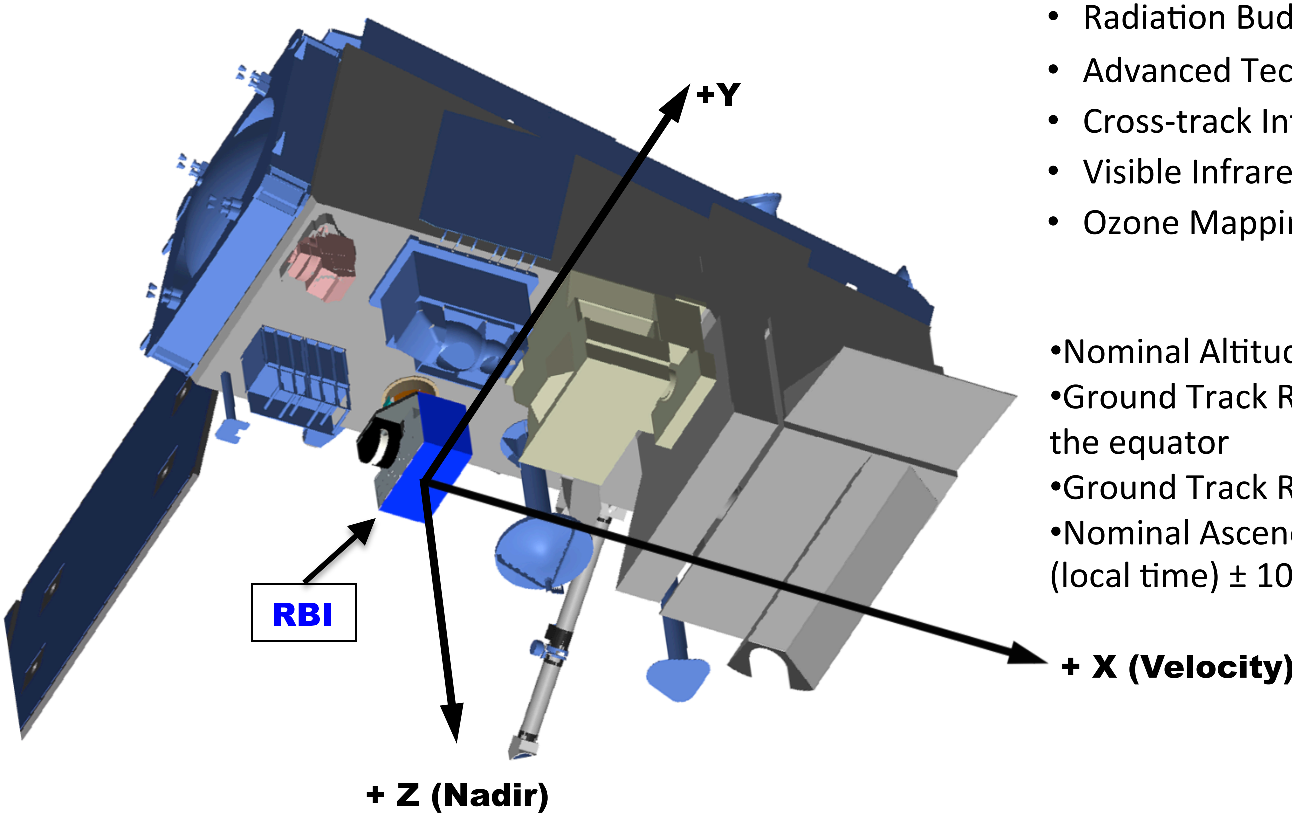
GENERAL DYNAMICS
Global Imaging Technologies

RBI Baseline and Threshold Requirements

Key Performance Requirements	Baseline Science Requirements	Threshold Science Requirements
Total Spectral Range	0.3 to 100+ microns	0.3 to 50+ microns
Shortwave Spectral Range	0.3 to 5 microns	0.3 to 5 microns
Longwave Spectral Range	5 to 50+ microns	5 to 35+ microns
Total Channel Absolute Radiometric Accuracy	≤ Larger of 0.575 W/m^2-sr or 0.5% (k = 1)	≤ Larger of 0.575 W/m^2-sr or 0.75% (k = 1)
Shortwave Channel Absolute Radiometric Accuracy	≤ Larger of 0.75 W/m^2-sr or 1.0% (k = 1)	≤ Larger of 0.75 W/m^2-sr or 1.25% (k = 1)
Longwave Channel Absolute Radiometric Accuracy	≤ Larger of 0.575 W/m^2-sr or 0.5% (k = 1)	≤ Larger of 0.575 W/m^2-sr or 0.75% (k = 1)
Total Channel Radiometric Precision	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	≤ 0.2 W/m^2-sr + 0.1% (k = 2)
Shortwave Channel Radiometric Precision	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	≤ 0.2 W/m^2-sr + 0.1% (k = 2)
Longwave Channel Radiometric Precision	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	≤ 0.2 W/m^2-sr + 0.1% (k = 2)
Total Channel Linearity	≤ 1.5 W/m^2-sr	≤ 2.5 W/m^2-sr
Shortwave Channel Linearity	≤ 1.28 W/m^2-sr	≤ 2.13 W/m^2-sr
Longwave Channel Linearity	≤ 0.54 W/m^2-sr	≤ 0.9 W/m^2-sr
Point Spread Function	Within 95% of CERES	Within 90% of CERES

RBI Baseline Science Requirements Match CERES

RBI Accommodated on JPSS-2 Spacecraft Nadir Deck



JPSS-2 Instrument Complement

- Radiation Budget Instrument (RBI)
- Advanced Technology Microwave Sounder (ATMS)
- Cross-track Infrared Sounder (CrIS)
- Visible Infrared Imaging Radiometer Suite (VIIRS)
- Ozone Mapping and Profiler Suite (OMPS)

JPSS-2 Observatory

•Nominal Altitude: 824 km ± 17 km
•Ground Track Repeatability Accuracy: ±20 km at the equator
•Ground Track Repeat Cycle: <20 days
•Nominal Ascending Equator Crossing Time: 1330 (local time) ± 10 min

Spacecraft design and Instrument locations are notional and representative of JPSS-1
JPSS-2 configuration has not been determined

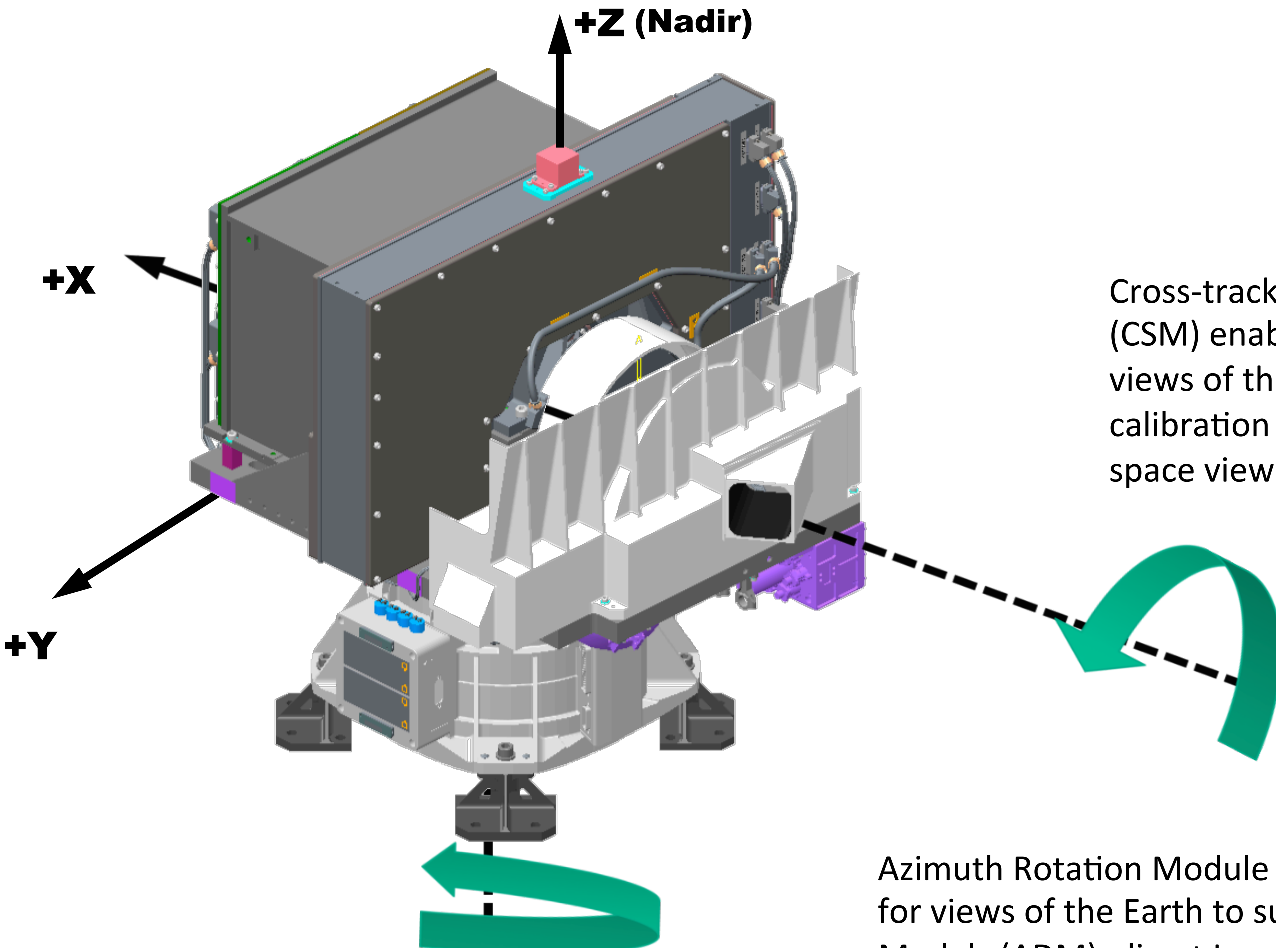
Instrument Overview

- **Instrument Design Overview**
  - Instrument Features
  - ConOps Overview
- **Performance Overview**
- **Schedule Status**
- **Radiometric System Model Status**

RBI ConOps Provides Operational Flexibility

- **Earth observations: Crosstrack and Biaxial scanning**
- **Calibration**
  - Every scan line: space look
  - Daily: single point gain response using Visible Calibration Target (VCT) and Infrared Calibration Target (ICT)
  - Monthly
    - Spectral calibration using VCT
    - Linearity measurement using VCT and ICT
- **User-defined modes for operational flexibility**
  - Earth target for validation campaigns
    - Includes cross-correlations with CERES by viewing the same earth location
  - Solar observations via diffuse Solar Calibration Target (SCT)
  - Lunar observations

Field of Regard Obtained by Mounting Orientation & Two-Axis Pointing



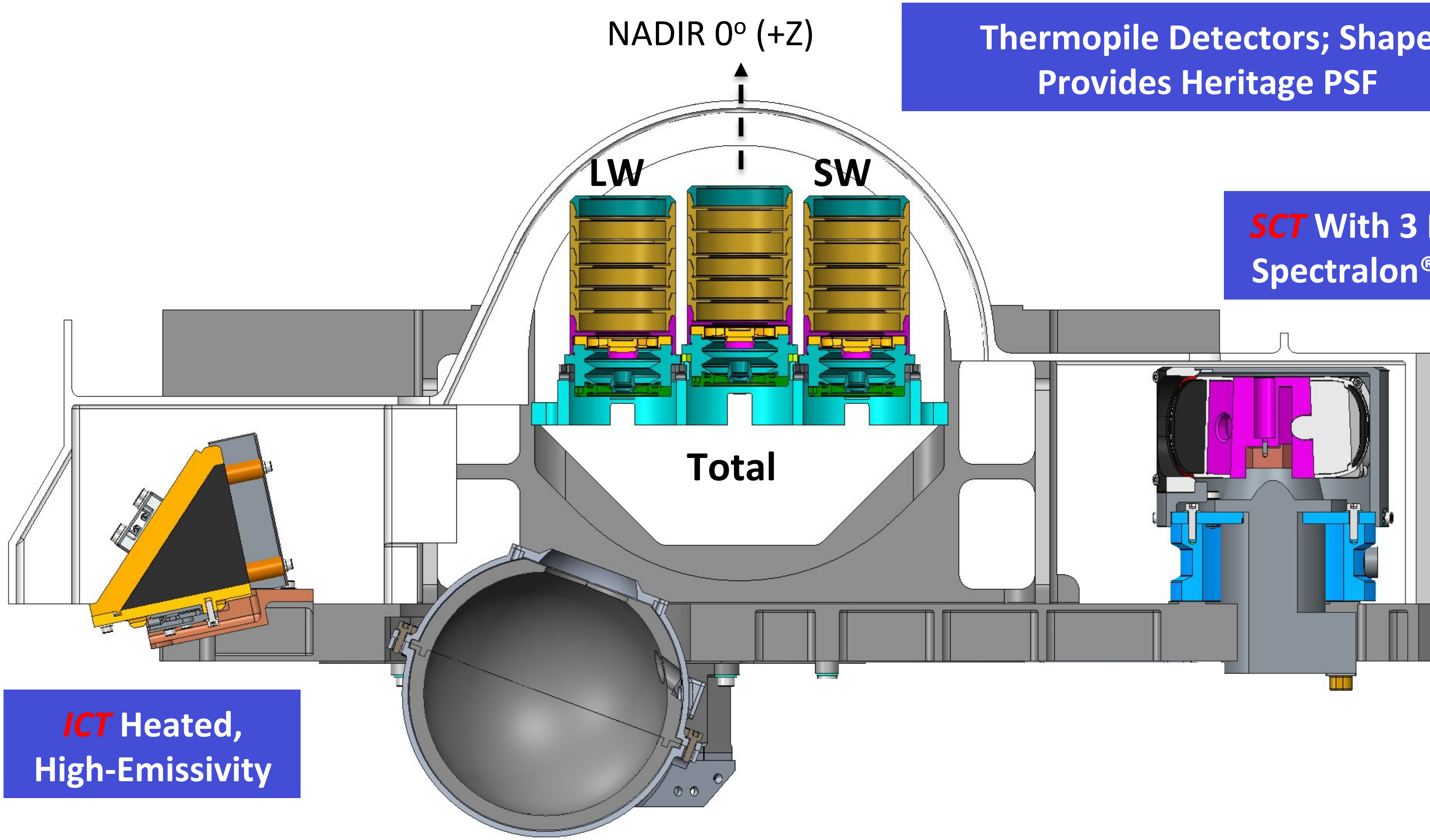
Cross-track Scan Module (CSM) enables swath mode views of the Earth, internal calibration targets, and space views

Azimuth Rotation Module (ARM) enables biaxial-mode for views of the Earth to support Angular Distribution Models (ADM), direct Lunar calibration, and indirect Solar calibration using the Solar Calibration Target (SCT)

Optical Modules and Targets Designed for Maximum Stability and Accuracy

Thermopile Detectors; Shape Provides Heritage PSF

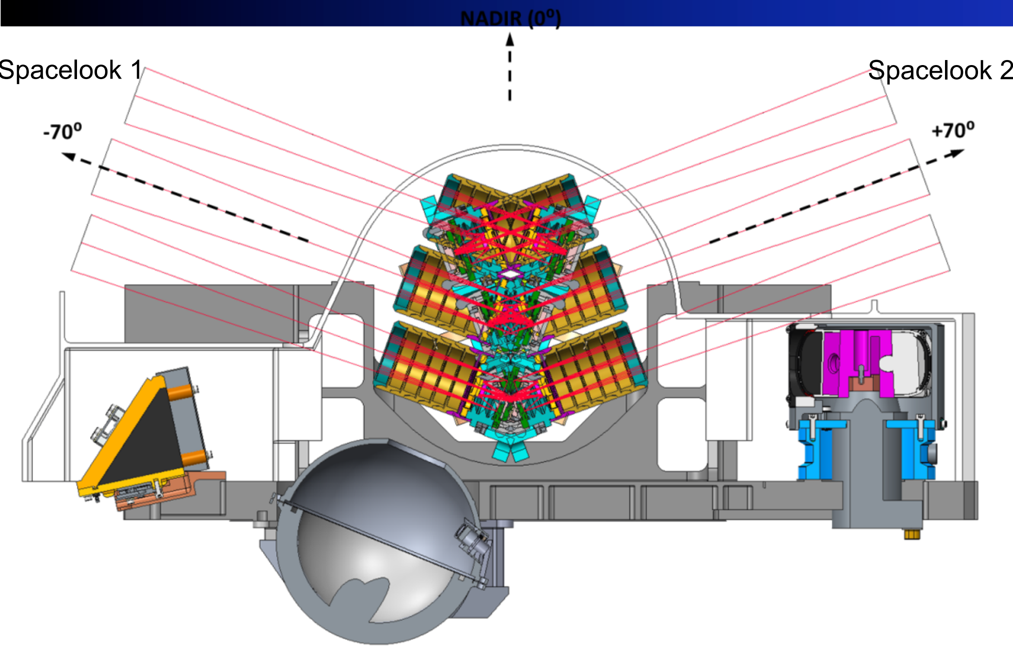
SCT With 3 Protected Spectralon® Surfaces

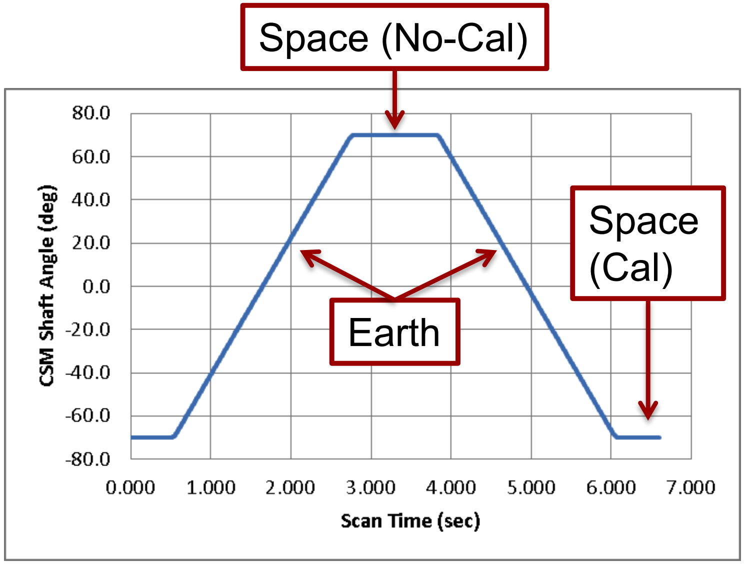


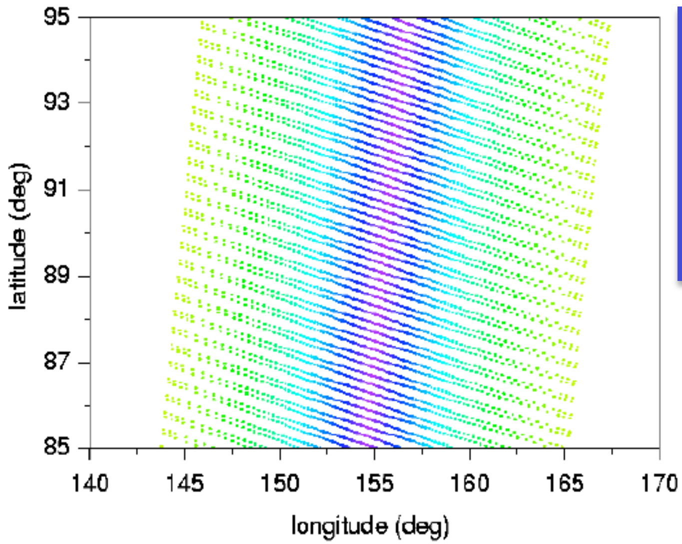
ICT Heated, High-Emissivity

VCT With 6-Wavelength Radiance Output and ESR for Absolute Reference

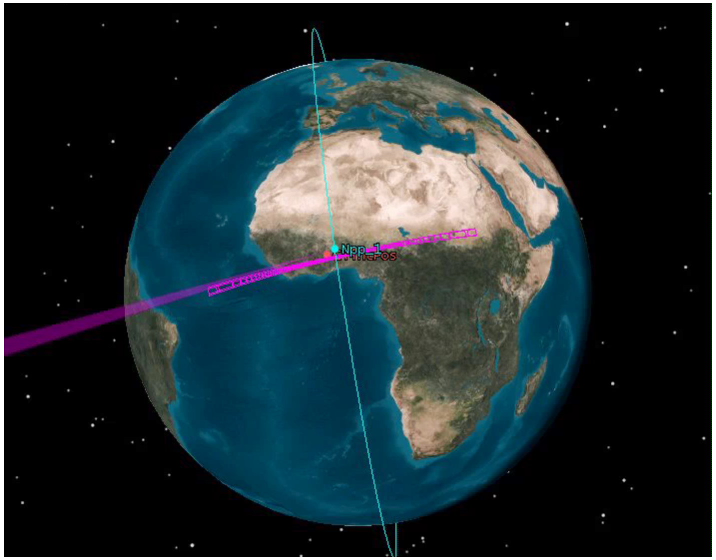
Cross-Track Scan is Primary Operational Mode





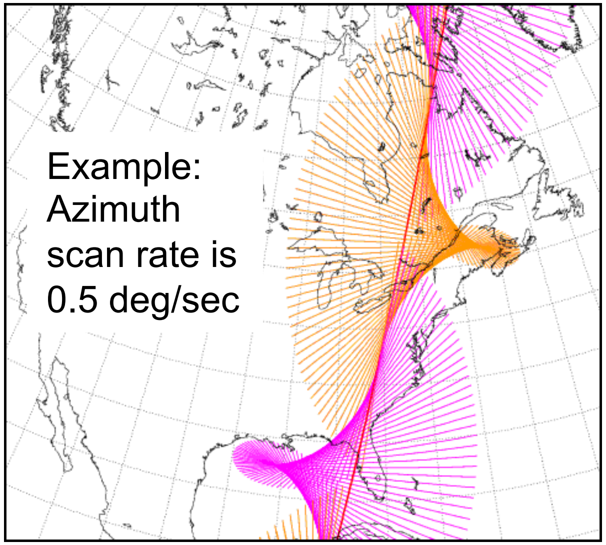


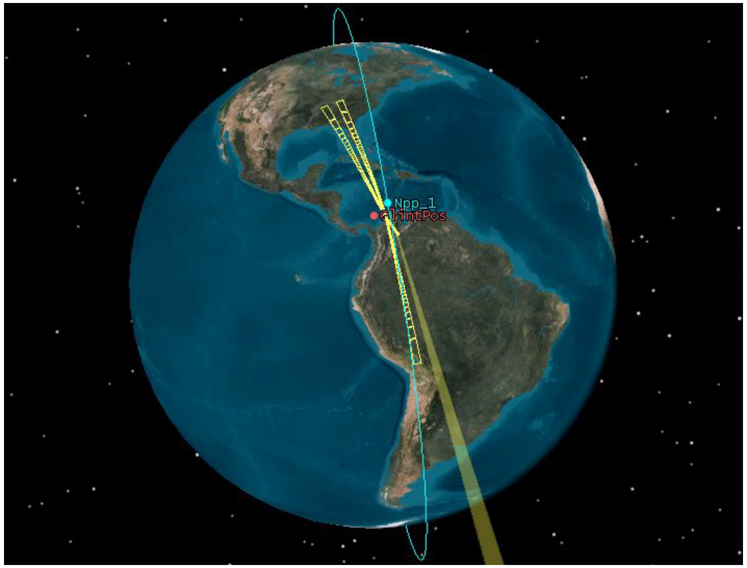
Constant 63.1 deg/sec rate over full Earth; 6.6-sec cycle time



Bi-Axial Scan Mode Supports Refinement of Angular Distribution Models

- **During a Bi-axial scan the instrument is commanded to rotate both the azimuth and Elevation gimbals**
  - Data is used to validate and refine Angular Distribution Models used to convert RBI radiances into fluxes at top of atmosphere
- **Elevation scan rate is 63.1 deg/sec with a +/- 70 deg rotation**
- **Azimuth scan rate is 0.5 to 6.0 deg/sec with a +/-90 deg rotation**
- **Azimuth scan rate and rotation are commanded from ground**





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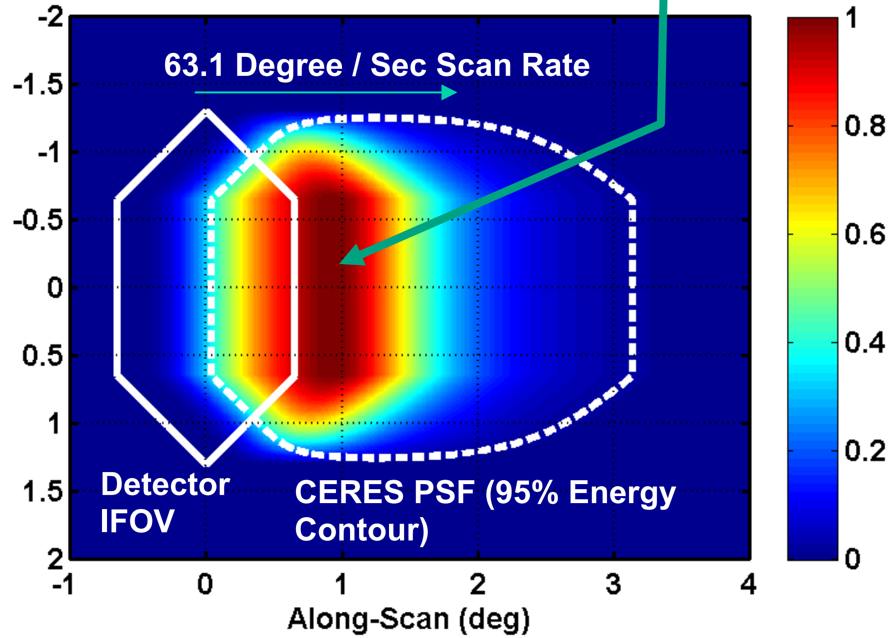
CERES-Like Point Spread Function (PSF) Provides Important Data Continuity

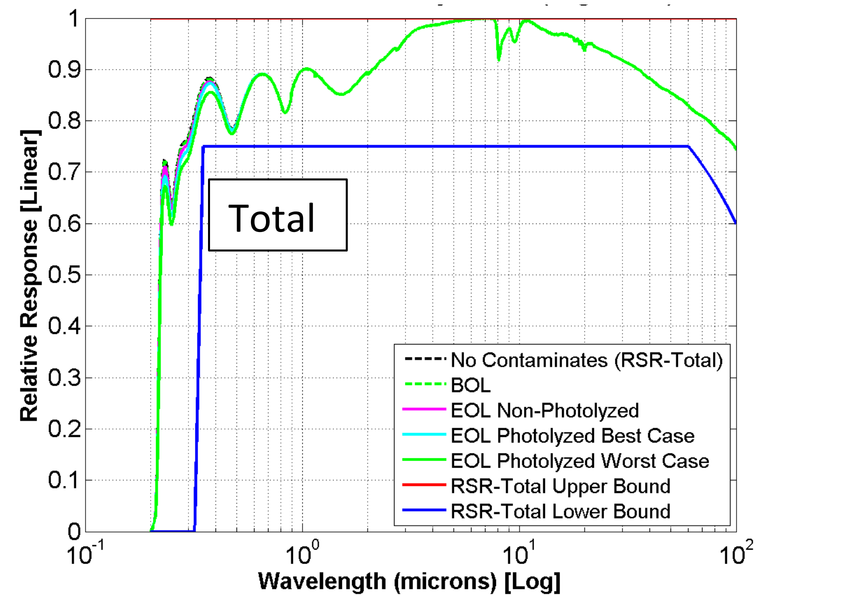
- **RBI detector shape mimics the CERES precision aperture, and heritage scan rate and time constant provides best PSF match**
- **RBI PSF is required to be smaller than CERES, referenced to 95% energy contour**
  - i.e., over 95% of RBI energy must be within the CERES 95% energy contour
- **Close match to CERES PSF enhances data continuity**

95.2% of RBI Energy Falls Within the Heritage CERES Contour (Worst-Case)

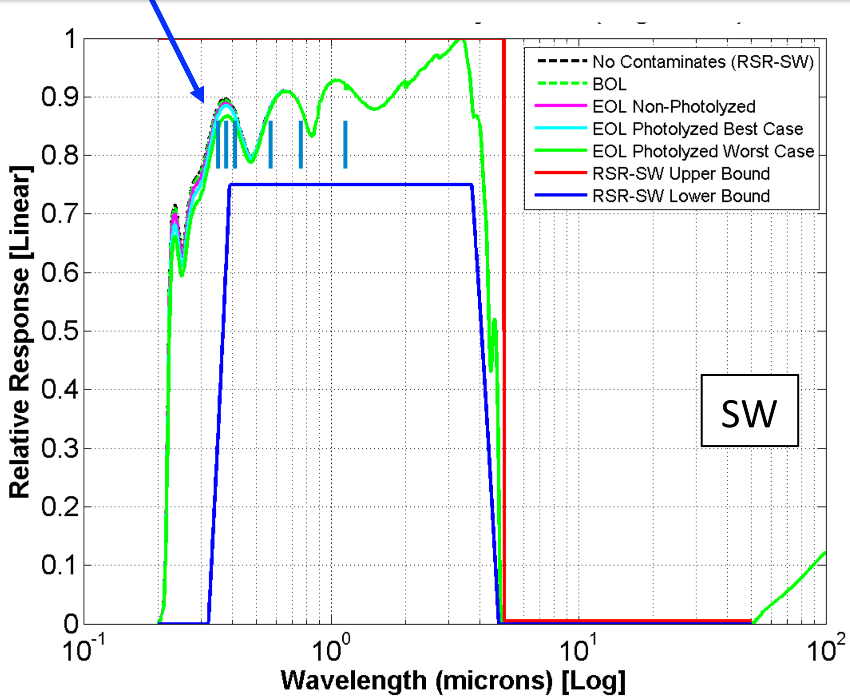


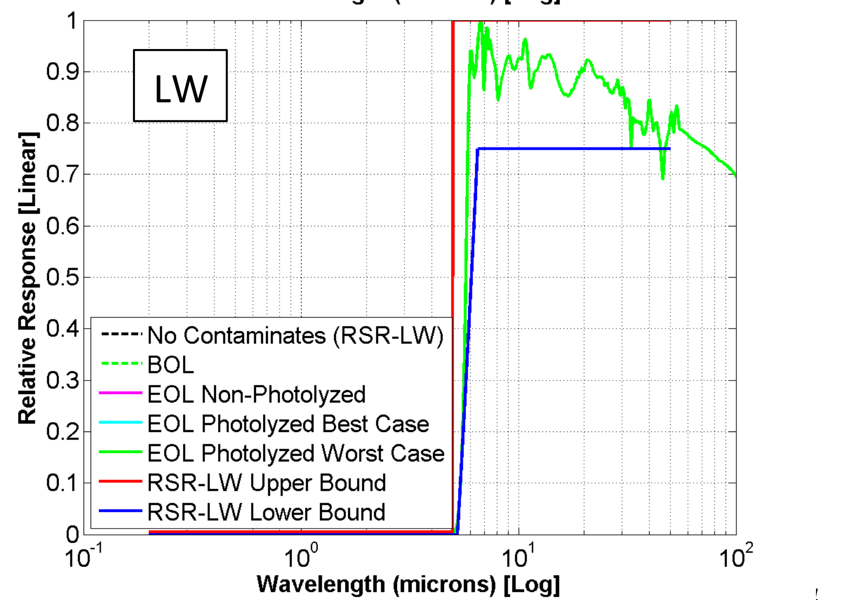
Knowledge of Relative Spectral Response Ensures Accurate Observations

- **VCT detects changes in Relative Spectral Response (RSR) over life allowing corrections to be implemented**
- **SCT can also support corrections**
- **ICT supports detection of change in the IR**

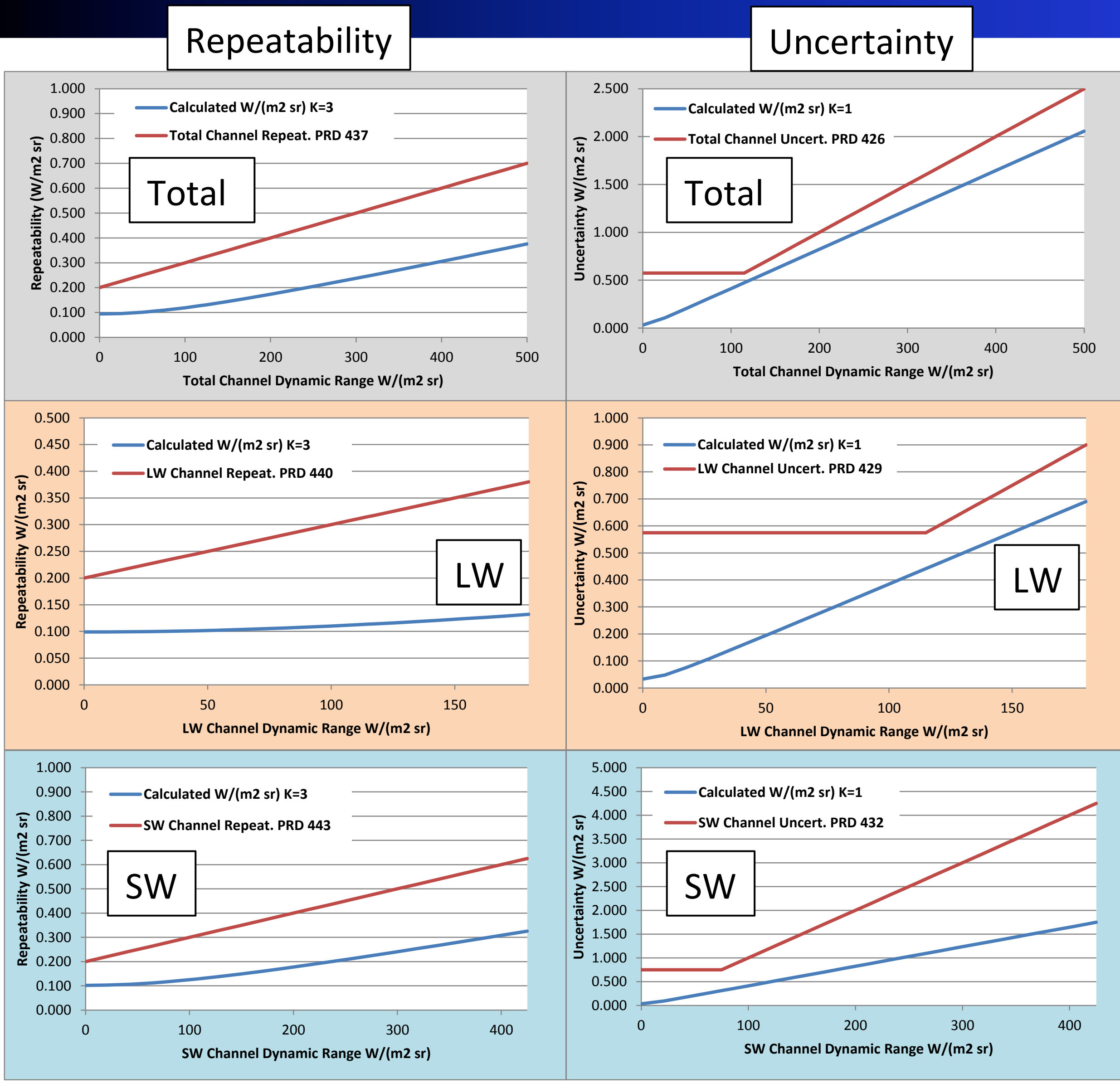


VCT Measures Responsivity Changes at 6 Wavelengths, Allowing RSR Changes to Be Corrected

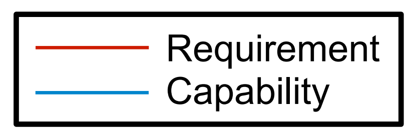




Radiometric Performance Expected to Meet Requirements



- Radiometric repeatability and uncertainty are expected to meet requirements
- Accurate radiance measurements are critical to the ERB CDR



RBI Expected to Satisfy Science Requirements

Key Performance Requirements	Baseline Science Requirements	Predicted RBI Capability
Total Spectral Range	0.3 to 100+ microns	0.3 to 100 microns
Shortwave Spectral Range	0.3 to 5 microns	0.3 to 5 microns
Longwave Spectral Range	5 to 50+ microns	5 to 50 microns
Total Channel Absolute Radiometric Uncertainty	≤ Larger of 0.575 W/m^2-sr or 0.5% (k = 1)	Compliant– See Previous Page
Shortwave Channel Absolute Radiometric Uncertainty	≤ Larger of 0.75 W/m^2-sr or 1.0% (k = 1)	Compliant– See Previous Page
Longwave Channel Absolute Radiometric Uncertainty	≤ Larger of 0.575 W/m^2-sr or 0.5% (k = 1)	Compliant– See Previous Page
Total Channel Radiometric Repeatability	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	Compliant– See Previous Page
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Longwave Channel Radiometric Repeatability	≤ 0.2 W/m^2-sr + 0.1% (k = 3)	Compliant– See Previous Page
Total Channel Linearity	≤ 1.5 W/m^2-sr	0.5 W/m^2-sr
Shortwave Channel Linearity	≤ 1.28 W/m^2-sr	0.43 W/m^2-sr
Longwave Channel Linearity	≤ 0.54 W/m^2-sr	0.18 W/m^2-sr
Point Spread Function	≥95% of CERES	95.2% of CERES, Worst Case

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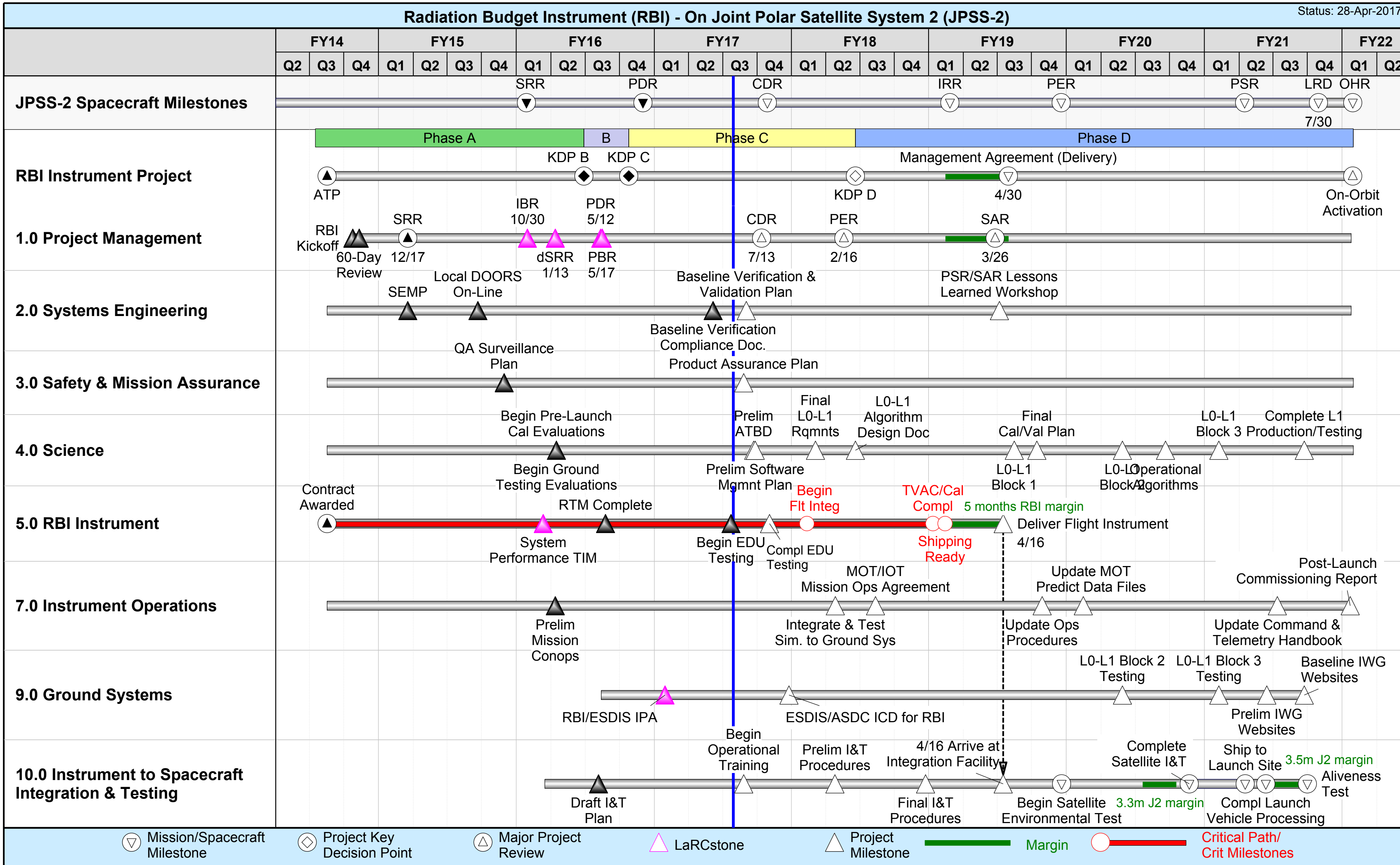
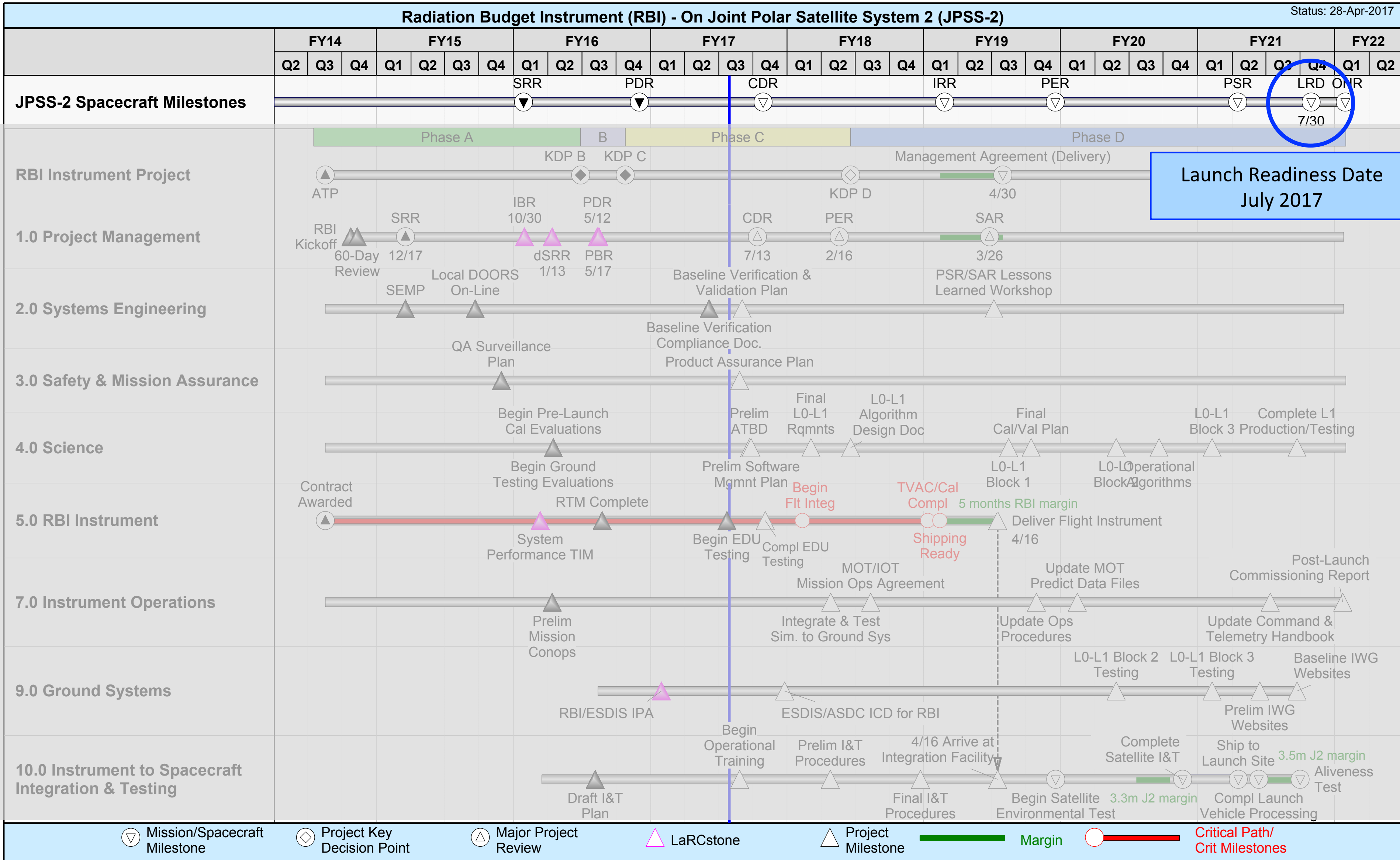
RBI Master Schedule

update with Harris in process



RBI Master Schedule

update with Harris in process



RBI Master Schedule

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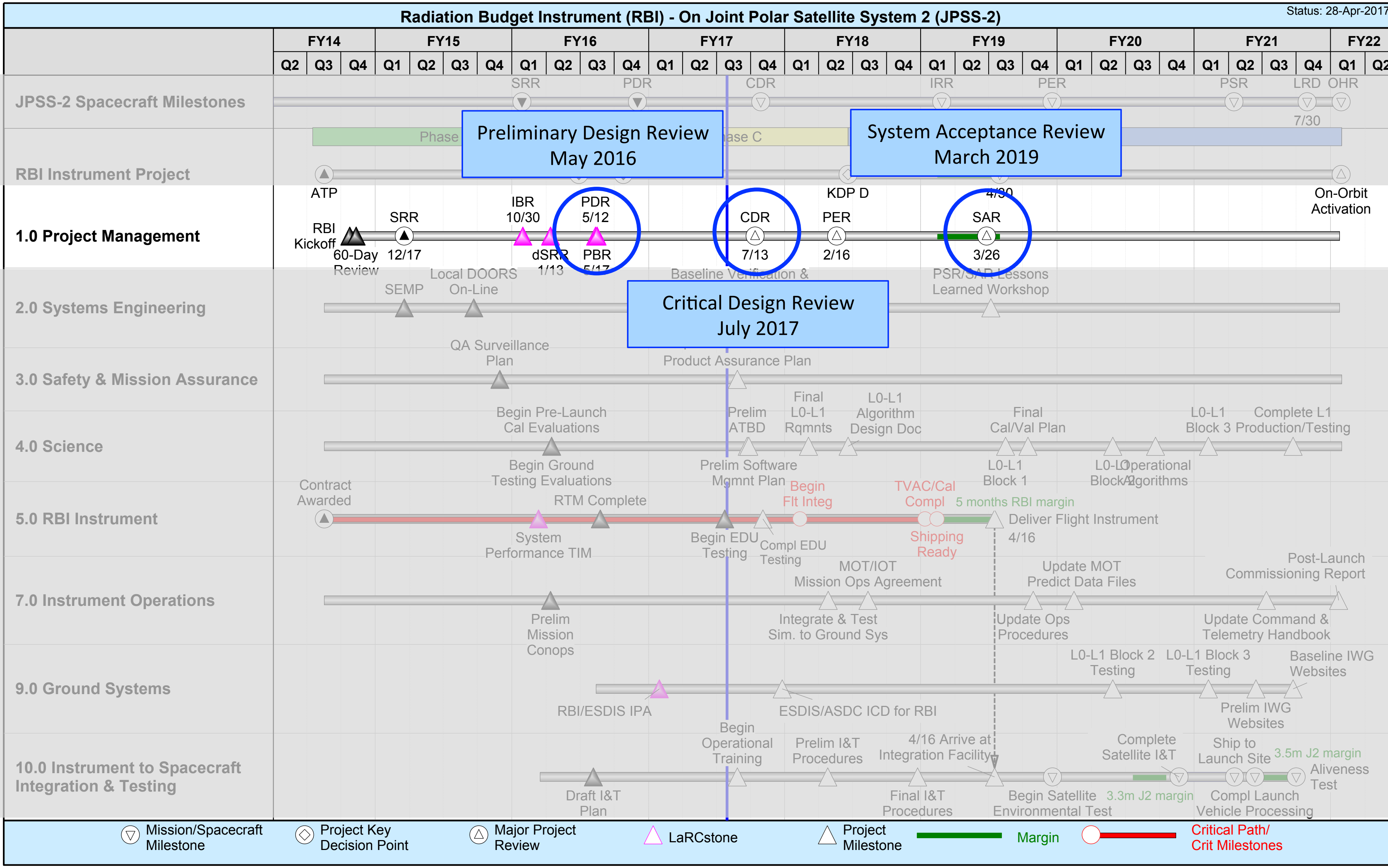
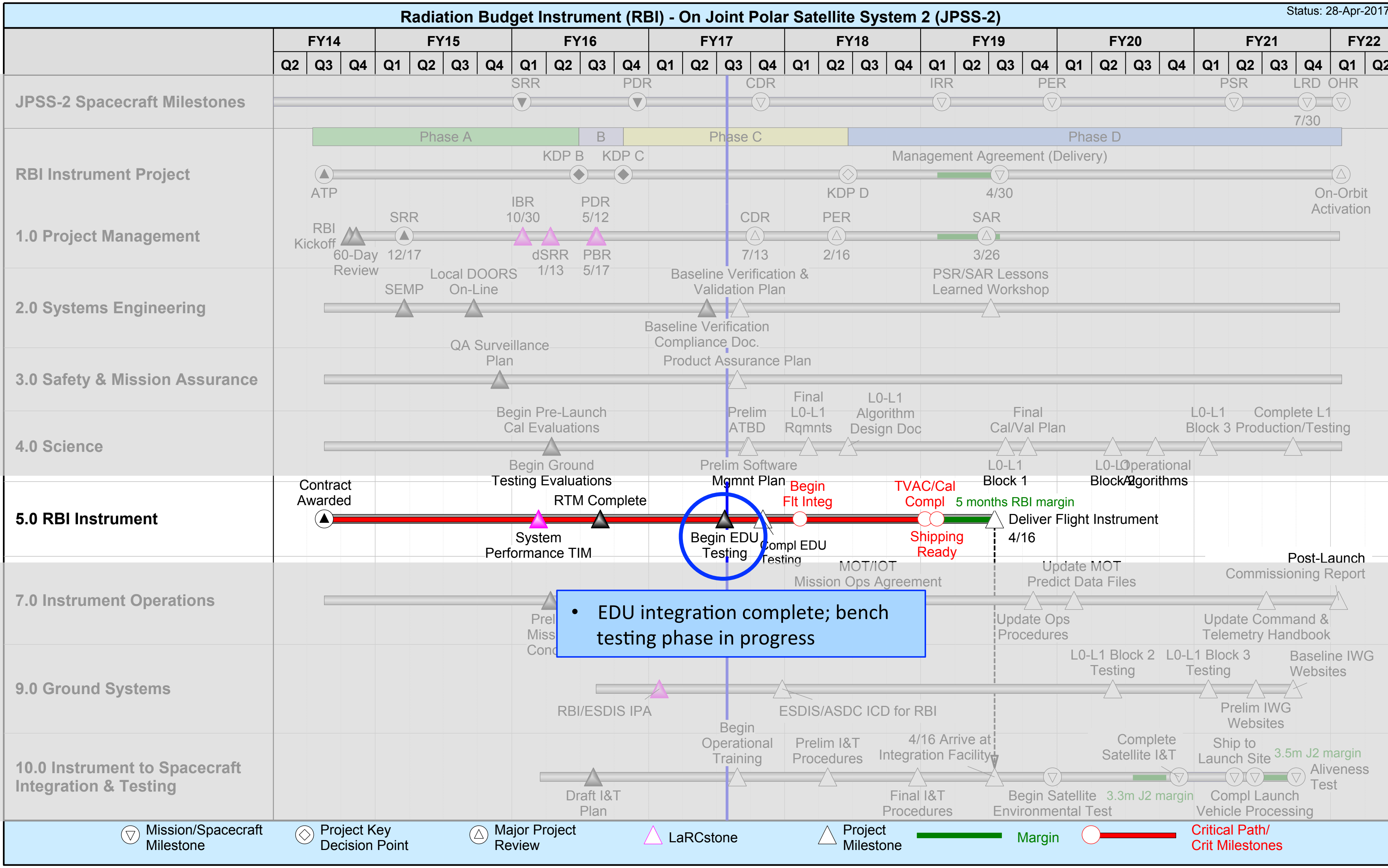
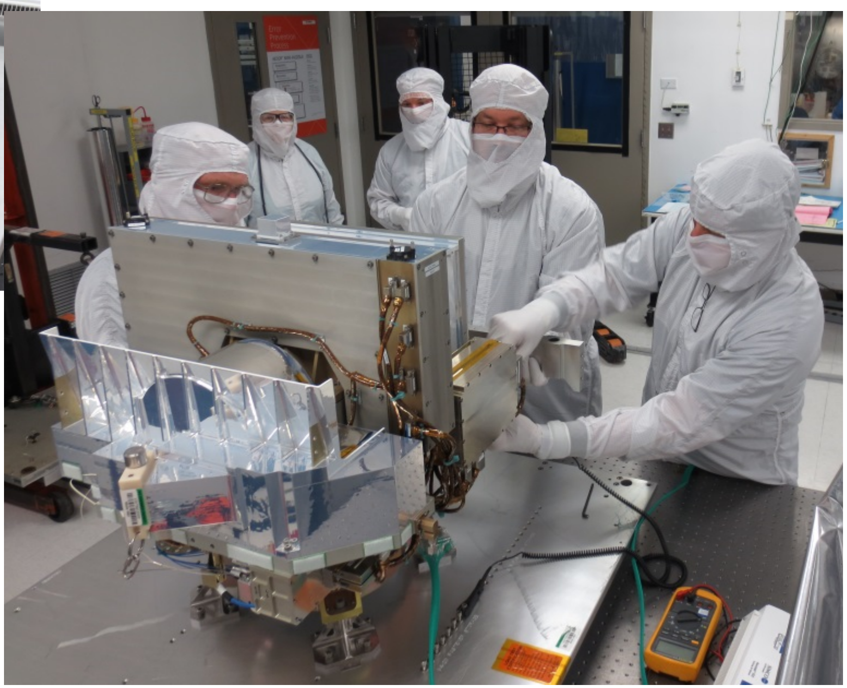


RBI Master Schedule

update with Harris in process



EDU Integration Complete



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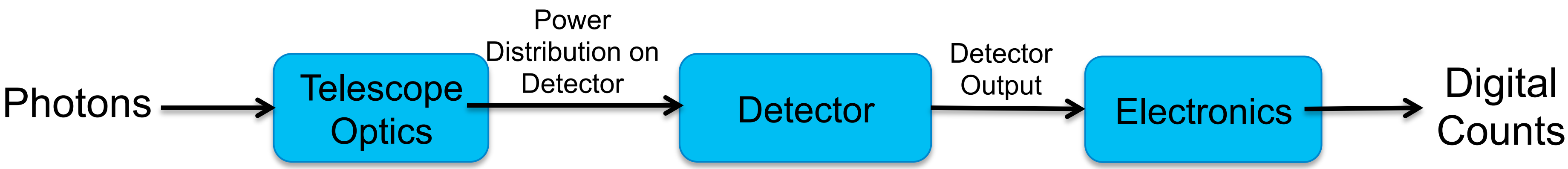
Radiometric System Model

Tool to enhance the interpretation of Instrument performance

- **Model the end-to-end science signal chain: Photons in to bits/counts out.**



- **Simulate the science data stream output when viewing *calibration targets*, *earth scenes* or any *user-defined radiance*.**
- **Support and validate engineering design and fabrication phase**
- **Quantify the effects of various anomalous sources of energy: stray light**
- ***Perform analyses as required to evaluate and quantify the impact to science data due to other uncertainties.***

Model Status and Future Work

- Currently in Build 2 phase: All subassemblies are developed in their respective platforms.
  - ✓ Design changes are being incorporated as engineering drawings become available
- Scene generator between calibration targets and telescope under development
- Thermal analysis preliminary results validates contractor's derived requirements for individual subsystems (ICT, telescope)
- Studies that can influence instrument design are being carried out in parallel
  - ✓ Stray light studies - **on-going to support flight re-design**
  - ✓ SW filter heating and re-emission - **complete**
  - ✓ Temperature variations in telescope baffles due to material change
  - ✓ ***Mis-alignment of focal plane modules may impact dynamic co-registration(NEW)***
    - **To be presented at Fall meeting**
  - ✓ Uncertainties in radiance arriving at telescope aperture due to:
    - View angles for all three telescopes to the sources.
    - Knowledge uncertainty in system parameters- temps, paint absorptivities, BRDFs, etc.

RBI Project Summary

- Harris has successfully powered-on the RBI Engineering Development Unit for the first time
- JPL-developed flight detectors have shipped to Harris
- RBI calibration facility at SDL is ready to support EDU testing
- CDR preparations on track for successful CDR July 11- 13, 2017
- Project and Harris are working closely together to develop a more realistic/ predictable / executable schedule
- Project is closely monitoring cost and schedule performance given tight fiscal status in FY17, particularly through threats
- Tail risks are a concern – PM is making decisions to maintain acceptable progress with higher than optimal risk posture

Back-Up

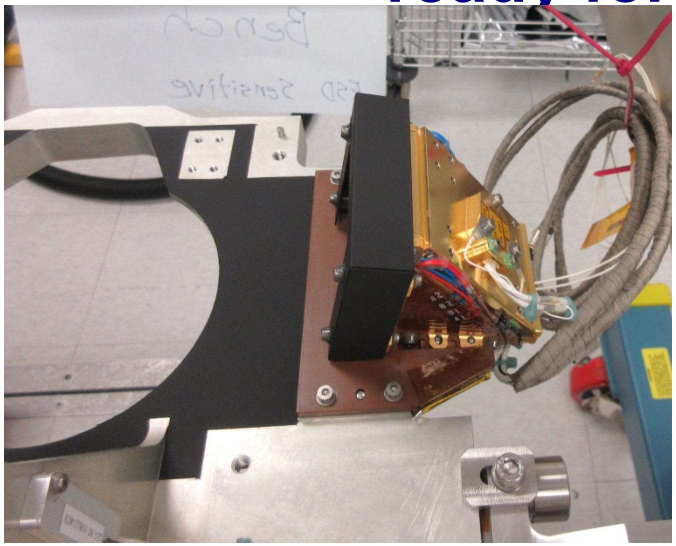
Numerical Modeling Tools

- **Monte-Carlo Ray-Trace Model**
  - Computes the distribution of radiation within the instrument.
  - Spectral characterization of the optical and radiative performance of the entire instrument.
  - Provides the necessary "Boundary" conditions for the thermal models.
- **Finite-Element Thermal Diffusion Model**
  - Three-Dimensional characterization of the transient thermal diffusion in instrument components
- **Finite-Difference Electro-thermal Model**
  - Three-Dimensional characterization of the transient thermal diffusion in the detectors
  - Two-Dimensional characterization of the transient electrical diffusion in the thermocouples.
- **Electrical Circuit Model**
  - Computation of the electronic Response of the electrical feedback control system.

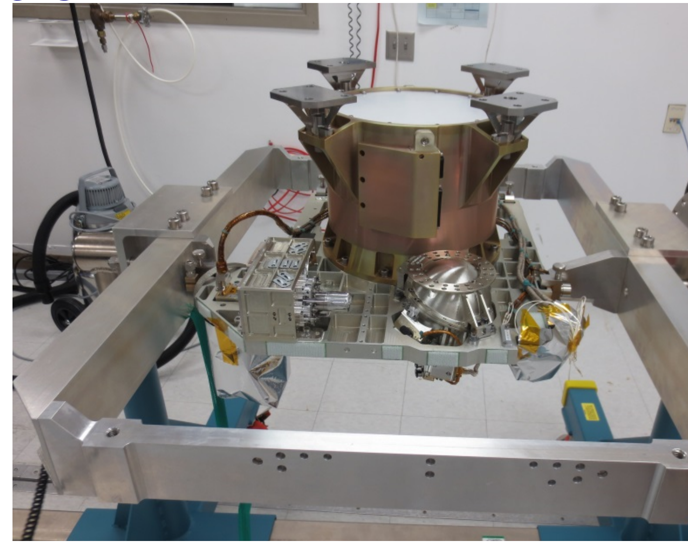
Previous Earth Radiation Budget (ERB) programs, such as CERES, have used these modeling tools for End-to-End characterization of the instrument

RBI EDU modules installed on bench – others ready for integration

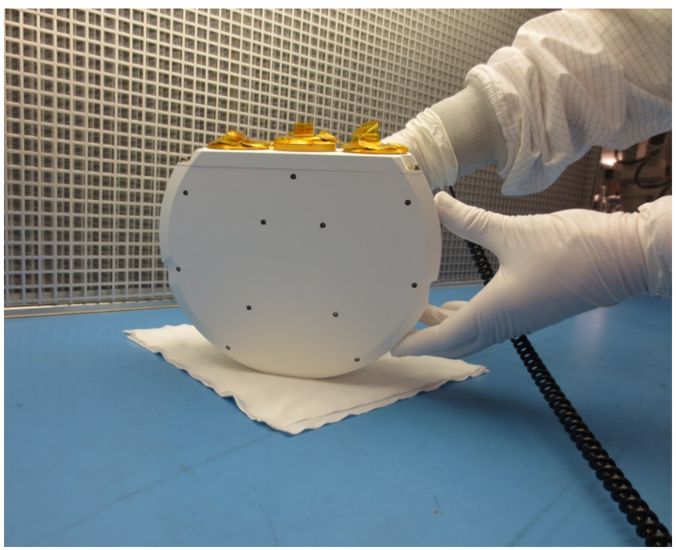
EDU ICT Installed on Bench



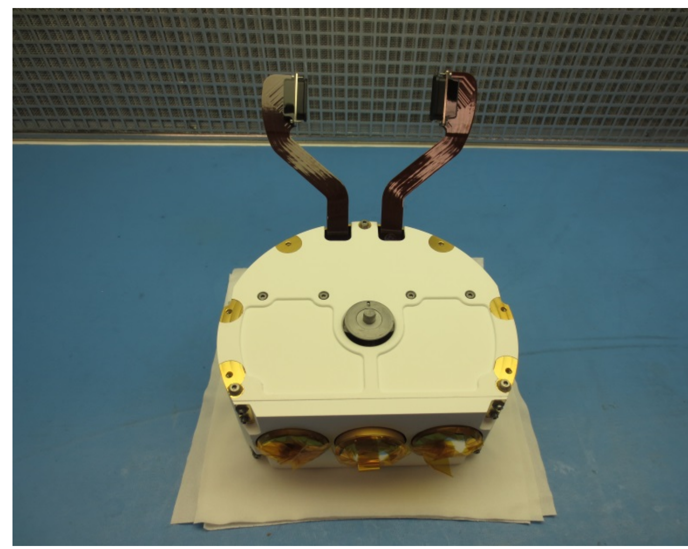
EDU VCT Installed on Bench



EDU Optical Module Ready for Integration



EDU Optical Module Ready for Integration

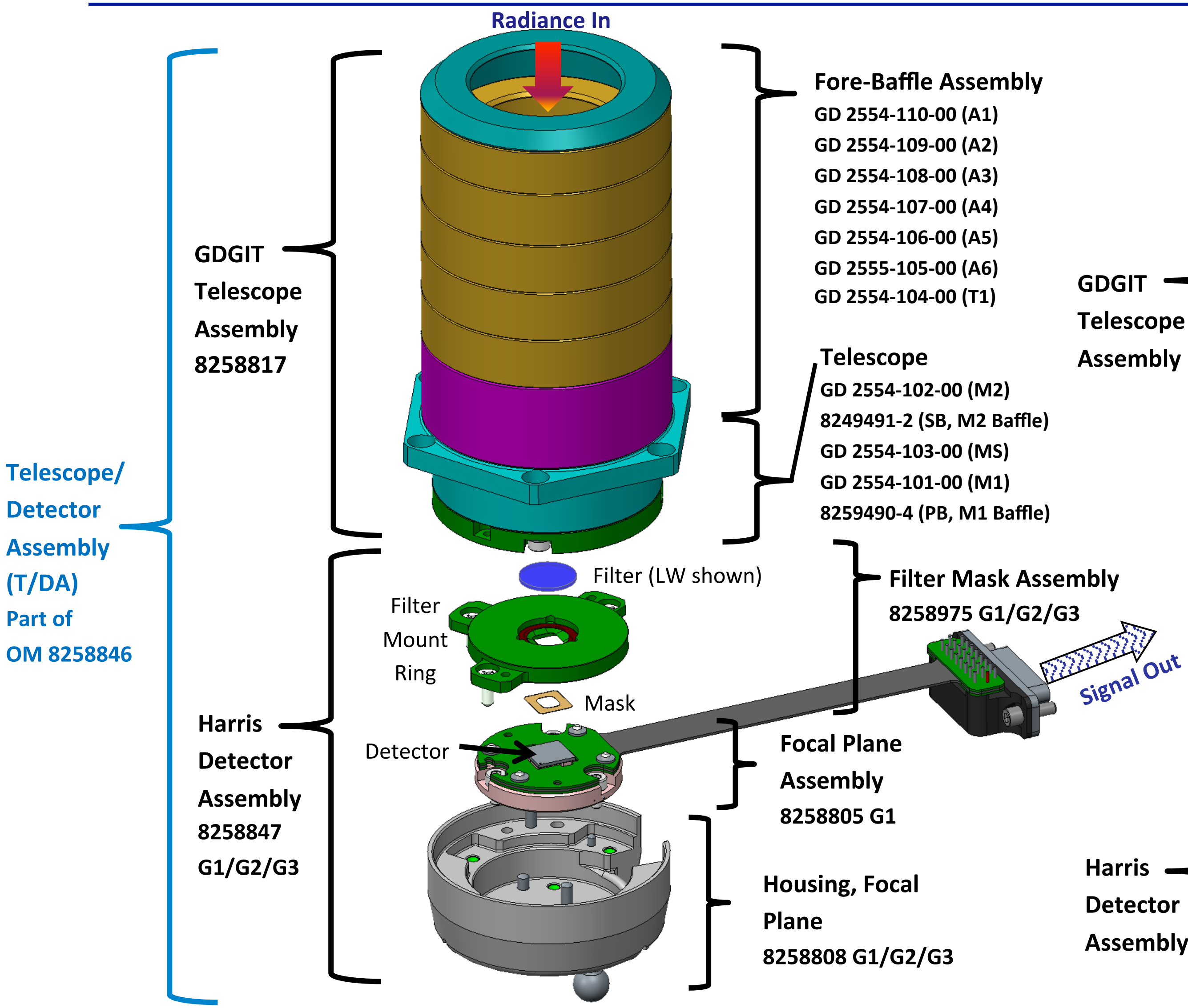


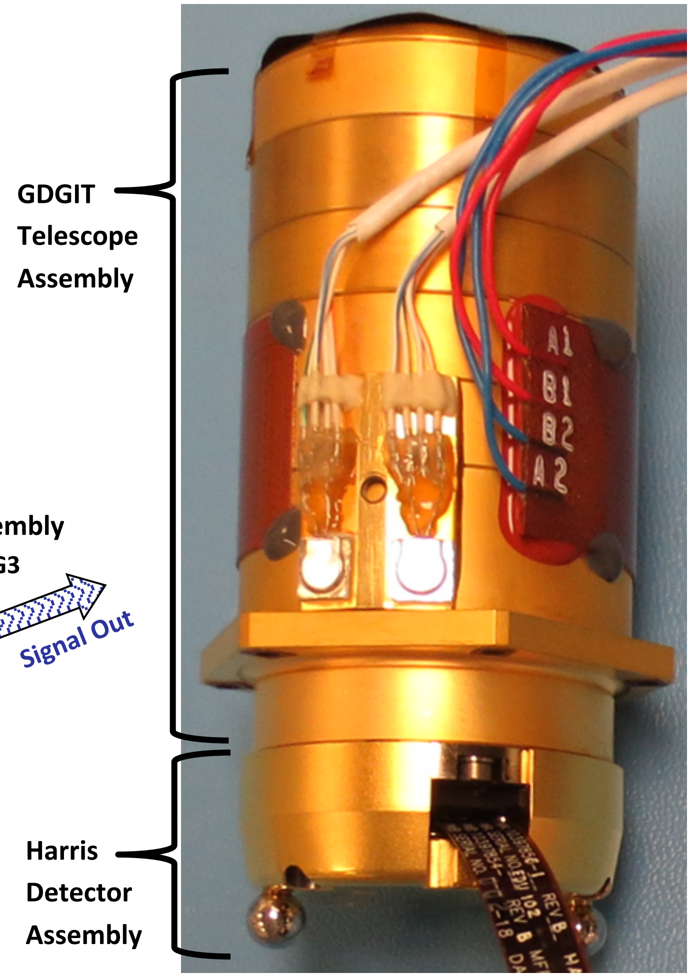
Upcoming Events

Dates	Description
4/18	System Thermal CDR (Harris – Fort Wayne, IN)
4/25	April PMR-Technical (Harris – Fort Wayne, IN)
5/2	EDU TVAC TRR (SDL-Logan, UT)
5/4	FPM PSR (JPL – Pasadena, CA)
5/9	Flight Vibration Test Kaizen (Harris – Fort Wayne, IN)
5/10	Electronics Unit (EU) Module CDR (Harris – Fort Wayne, IN)
5/16	Flight TVAC Kaizen (Harris – Fort Wayne, IN)
5/17	May PMR-Technical (Harris-Fort Wayne, IN)
5/25	CSM CDR (Harris-Fort Wayne, IN)
5/31	Calibration TIM (Harris – Fort Wayne, IN)

Dates	CDR Events
5/19	CDR ToR Complete
5/30	CDR Draft Walkthrough (Telecon)
6/8	June EPTR – CDR Readiness Assessment (LaRC)
6/9	SRB Readiness Assessment (LaRC)
6/14-15	CDR Dry Run (Telecon)
6/28	Final CDR Charts Posted
7/11-13 (TBR) 2017	System CDR (Harris-Fort Wayne, IN)

Optical Functionality of Telescope/Detector Assembly Assessed by Assembly & Components





Assembled EDU T/DA

Science and Continuity Drive Key Features of RBI Design

RBI Science Needs	RBI Design Feature to Fulfill Science Need
Low Shortwave Radiometric Uncertainty	***VCT*** containing Electrical Substitution Radiometer (ESR) provides stable SW reference radiance over life
Low Total and Longwave Radiometric Uncertainty	Heated high-emissivity ***ICT*** with well-calibrated temperature sensors provide on-orbit reference for Total and LW channels
Accurate Knowledge of Relative Spectral Response Over Life	6-diode ***VCT*** provides multispectral RSR characterization with absolute stability provided by the ESR
Radiometric Calibration Consistency Between Channels	All channels view the same ***VCT***, ***ICT*** and ***SCT***.
Stable Radiometric Response	Effective temperature stability of telescope and detectors
Point Spread Function (PSF) Closely Matches Heritage CERES	RBI uses an IFOV size/shape and scan rate that are nearly identical to heritage CERES. PSF closely matches CERES.
Radiometric Verification Via Solar Calibration	***SCT*** containing multiple Spectralon surfaces. Pristine surfaces are used to detect degradation of primary surface.
Multiple Observation Modes (crosstrack, bi-axial, user defined)	3 telescopes (one for each band) provide best operational flexibility and continuity. Uploadable scan pattern.
Reliable Science Data	Completely redundant instrument, including detectors and electronics

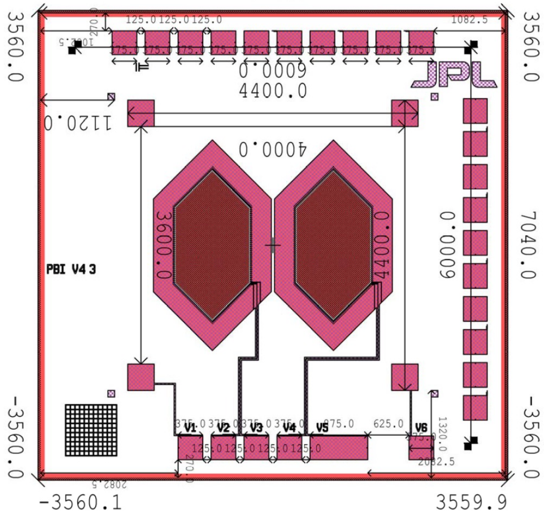
VCT = Visible Calibration Target

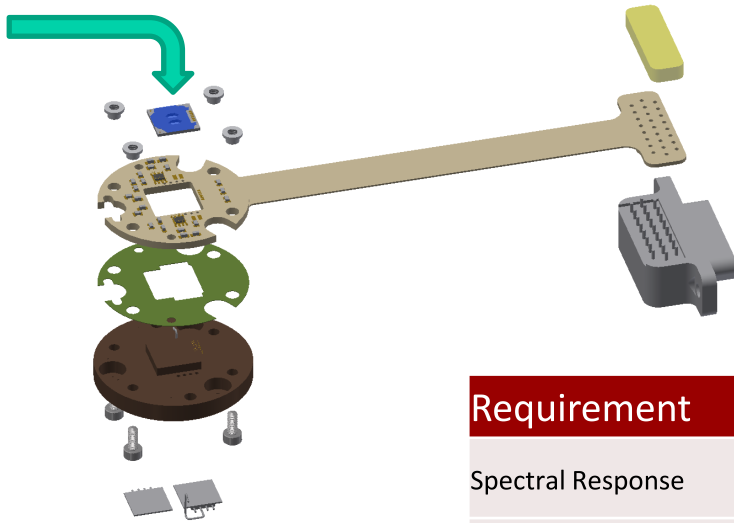
ICT = Infrared Calibration Target

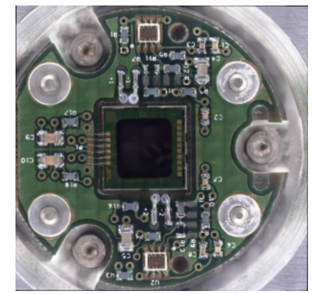
SCT = Solar Calibration Target

JPL Thermopile Detectors Enable Data Continuity with CERES

Radiation Budget Instrument





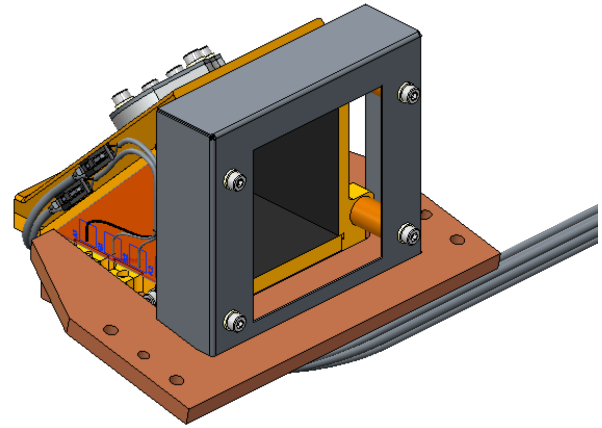


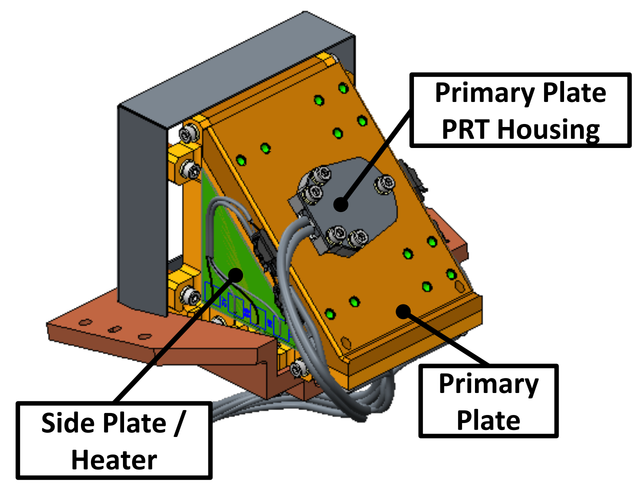
- **Uncooled thermopile detectors with Gold-Black coating are responsive over the full RBI spectral range from UV to far-infrared**
  - Scene radiance is measured by detecting small changes in temperature of the detector material
- **Detectors are highly linear, stable, low noise, and fully redundant**
- **Heritage: MCS/Diviner (15 years of flight ops)**

Requirement	Value	Compliance
Spectral Response	Specified over 0.2-100 microns	Yes
Dynamic Range	0-600 $W/m^2/sr$	Yes
Gain	22,000V/W +/-10%	Yes
Gain Temp Coefficient	≤220V/W/K	Yes
Reliability (glint survival)	3.81 mW, 30 times	Yes
Non-linearity	≤0.04%	Yes
Response Uniformity	+/-5% 3x 75um spot	Yes
Out of field response	≤0.01%	Yes
Noise Equivalent Power	≤3 nW	Yes
Time constant max	≤9.0 msec	Yes
Time constant min	≥7.5 msec	Yes
Output Stability	≤0.5nW for 6.6 sec	Yes

ICT is a Thermal Infrared Radiance Source for Precise Calibration

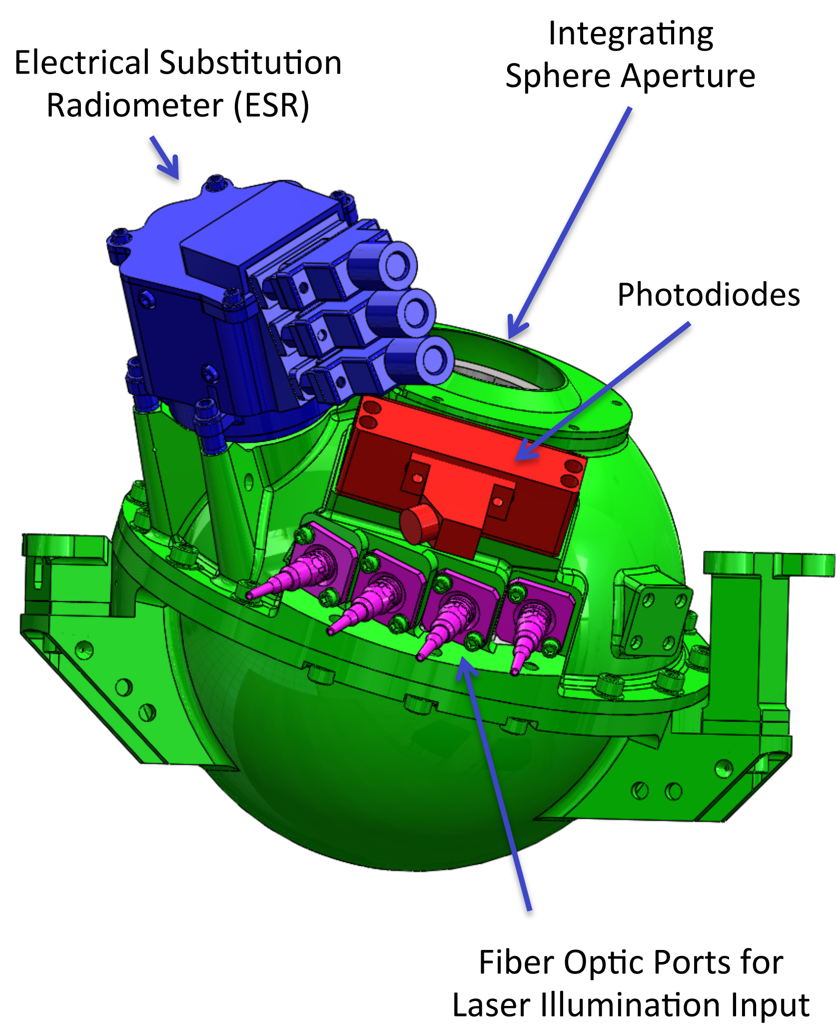
- Provides IR calibration source for LW and Total channels
- Harris-patented Specular Trap design provides >0.995 emissivity in a compact, easy to manufacture package
- PRTs are carefully calibrated to NIST standard on the ground prior to installation
- Heaters enable linearity measurements while on-orbit
- Beryllium minimizes thermal gradients
- Flight heritage design from CrIS and AHI-8





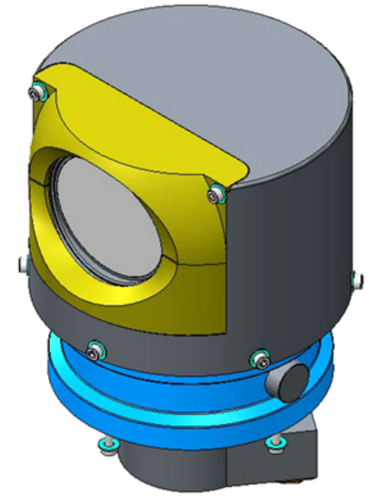
Visible Calibration Target Provides Reflected Solar Band Calibration Standard

- **VCT provides 6 laser diode sources**
  - 375, 405, 445, 690, 915, 1470 nm
  - Radiometric calibration uses 915nm laser only
  - RSR characterization uses all 6 wavelengths sequentially
- **Si and InGaAs photodiodes provide short-term radiance reference**
- **ESR provides stable absolute radiance traceable to NIST**
  - Used monthly to calibrate photodiodes and SW / Total channels
- **Laser diodes are remotely located, fiber coupled, providing thermal stability of diodes and sphere**

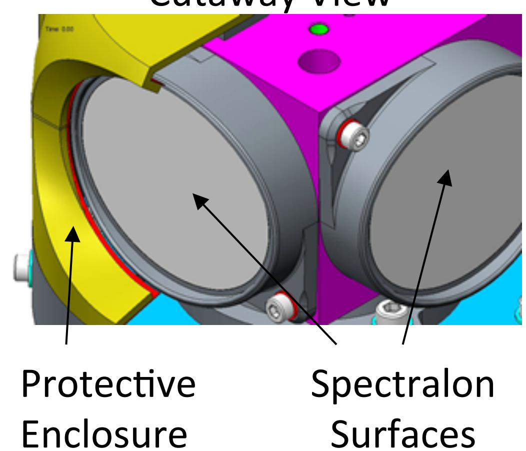


Solar Cal Target Provides Additional Independent Check of SW/Total Calibration

- **SCT contains three protected Spectralon® solar diffusers for on-orbit calibration checks**
  - Targets are in a cube orientation within a sealed enclosure, which protects them from solar degradation
  - At least one surface can be maintained in a pristine condition to track and correct for changes in the "daily" surface
  - The 4th face blocks incoming solar radiation and contamination when the SCT not in use
- **SCT mechanism is space-qualified**
- **Proven Spectralon® solar diffuser material, also used by ABI, AHI, COMS, and GOSAT programs**

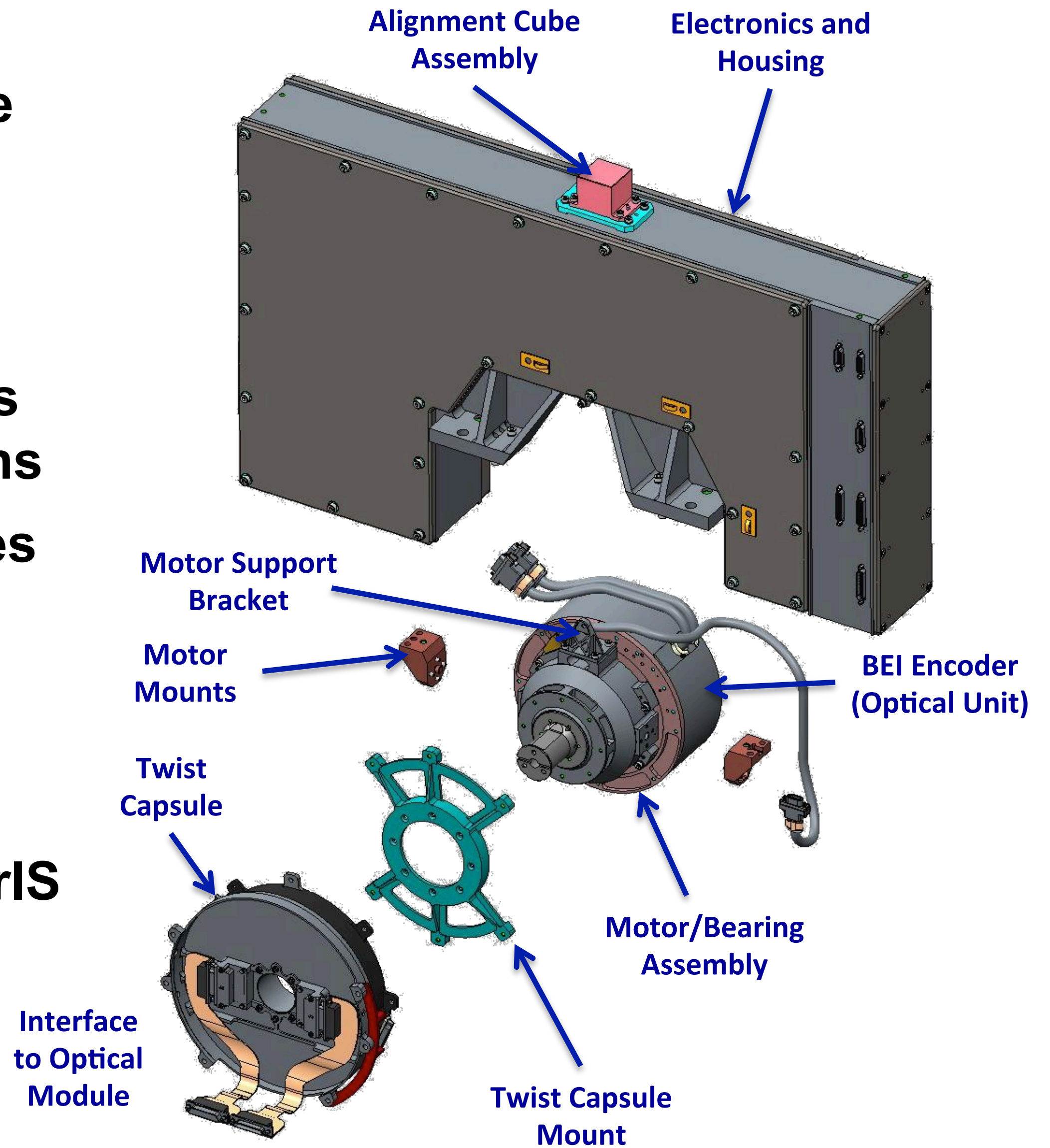


Cutaway View



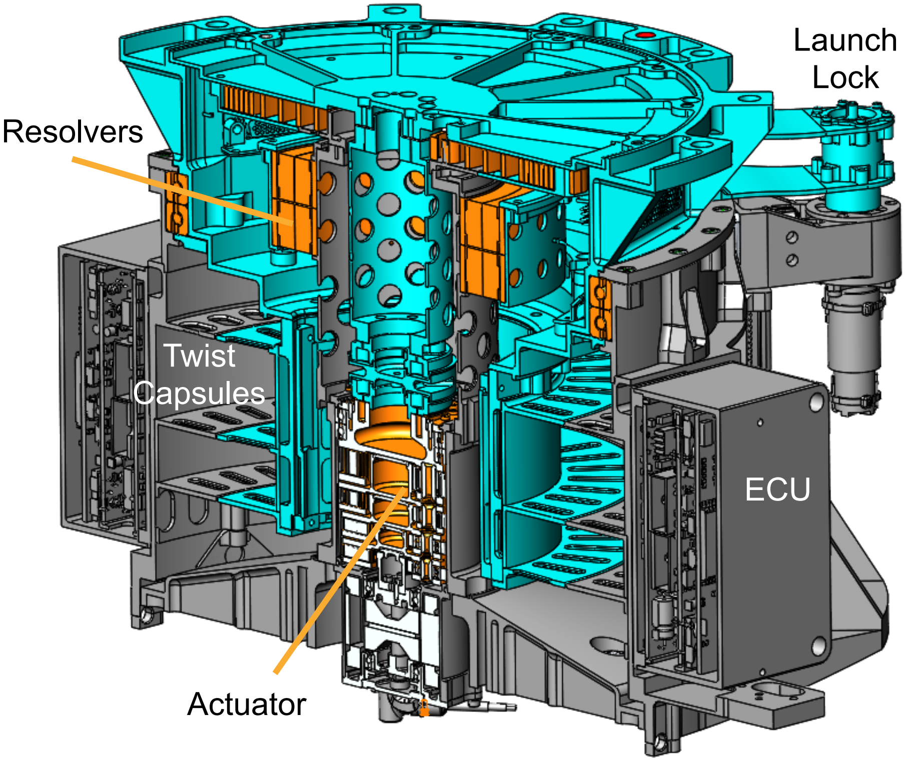
CSM Provides Low-Jitter Cross-Track Scanning of Optical Module

- Designs leverage heritage motor/ encoder designs
- Design optimizes OM thermal performance
- Twist flex design provides redundant OM connections
- H infinity control optimizes response and provides robustness to external disturbances
- Heritage bearing system has proven long life on CrIS



Azimuth Rotation Module Provides Reliable Bi-Axial Scan Capability

- **Provides azimuth rotation of upper half of instrument**
  - Rate of 0.5-6.0 deg/sec
- **Open-loop stepping system with simple and reliable control process**
- **Resolver feedback in telemetry provides confirmation of positioning**
- **Leverages many assemblies with flight heritage**
  - Gearbox, resolvers, hybrid stepper motor, Electronic Control Unit, launch lock



Gray = Stationary (Tied to Spacecraft)
Blue = Rotating With RBI Bench
Orange = Combination

Instrument Overview

- **Instrument Design Overview**
  - Instrument Features
  - ConOps Overview
  - Changes Since SRR
  - Module Overviews
- **Performance Overview**
- **Engineering Development Unit Overview**

Engineering Development Unit

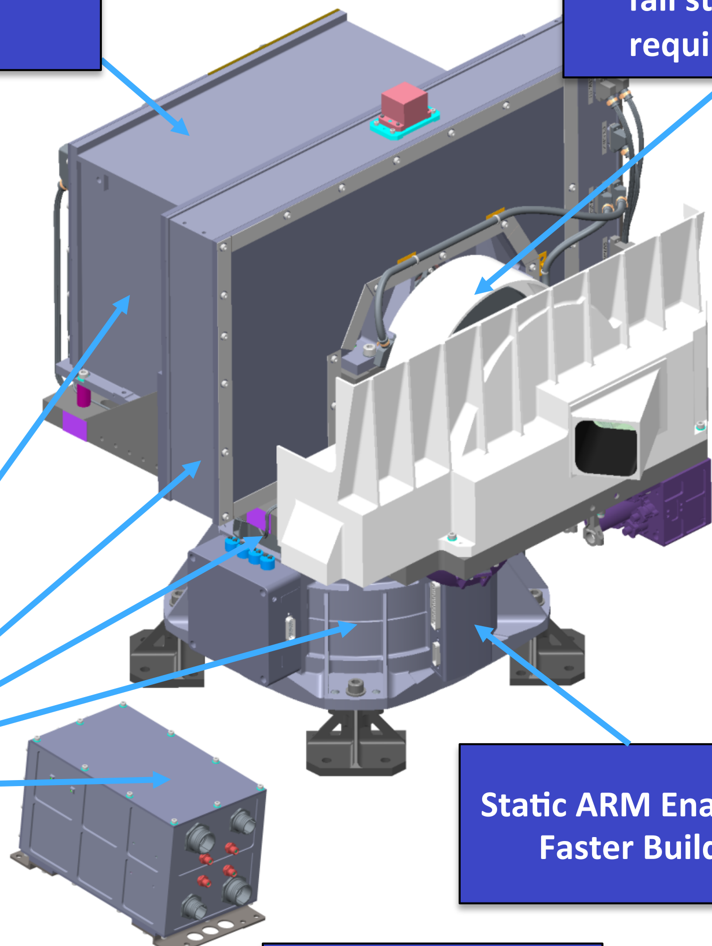
- **EDU is a pathfinder for calibration**
  - Design is quite similar to RBI flight design
  - Manufacturing processes are validated
  - Radiometric performance requirements are demonstrated
  - Calibration approach is demonstrated
- **EDU is a pathfinder for test execution**
  - “Dry Run” of the Flight pre-launch calibration campaign
  - Limited environmental tests bring confidence to design robustness
- **EDU TVAC Testing Scheduled for Summer 2017**
  - Provides first opportunity to correlate end-to-end radiometric model

EDU is a Representation of Flight Design

EDU

EDU Is Not electrically redundant

Optical Modules fail stray light requirements



Multiple Aluminum Substitutions to Enable Faster Build and Test

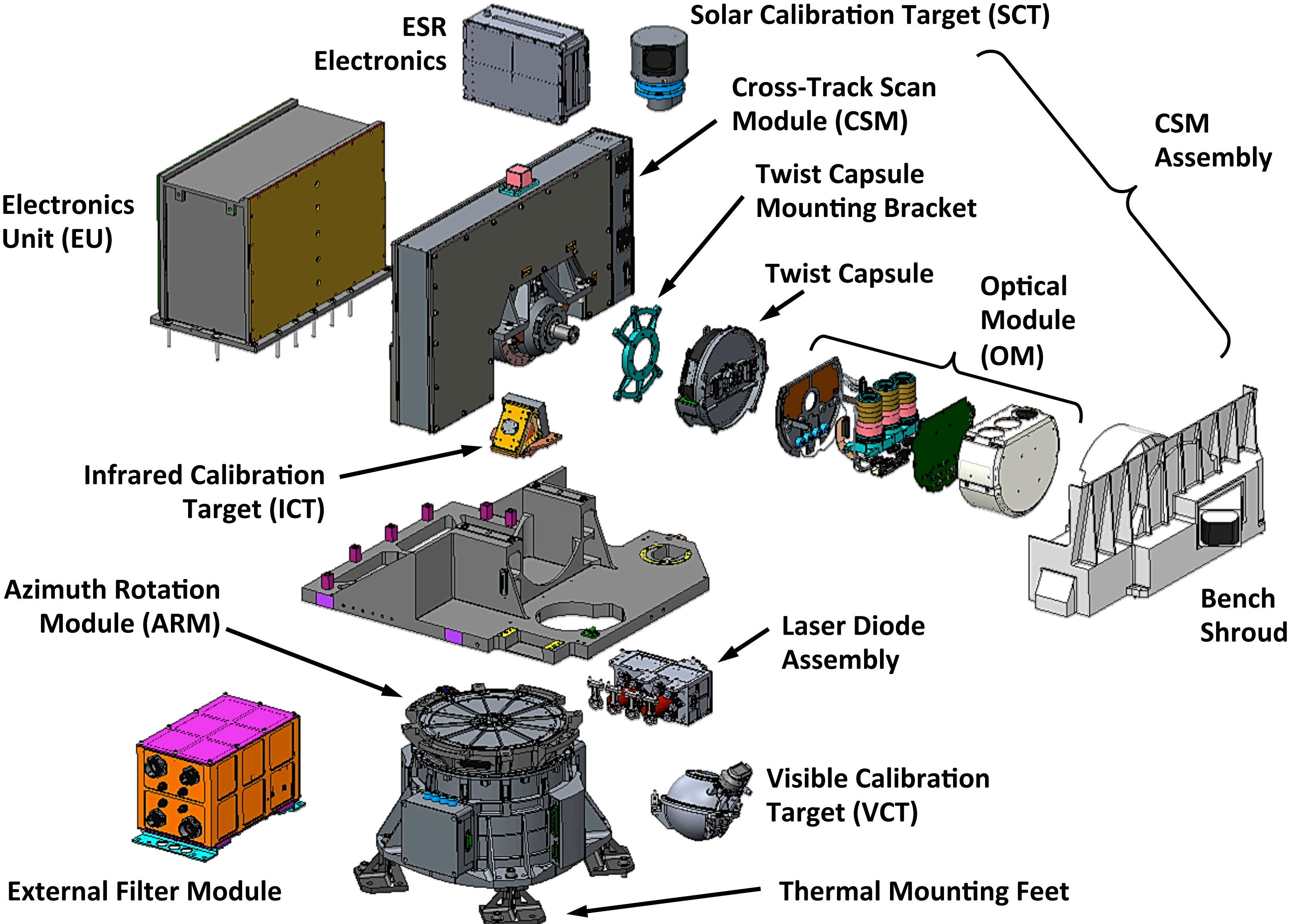
Static ARM Enables Faster Build

Quality Standards Are Specific to EDU-Type Build

Summary

- RBI design is optimized for its mission
- RBI provides valuable data continuity with CERES
- Operations are highly flexible to support science needs
- Design utilizes heritage sub-assemblies to minimize development risk and schedule
- Performance expected to meet requirements
- RTM and EDU provide early risk mitigation

Modular Design Simplifies Integration

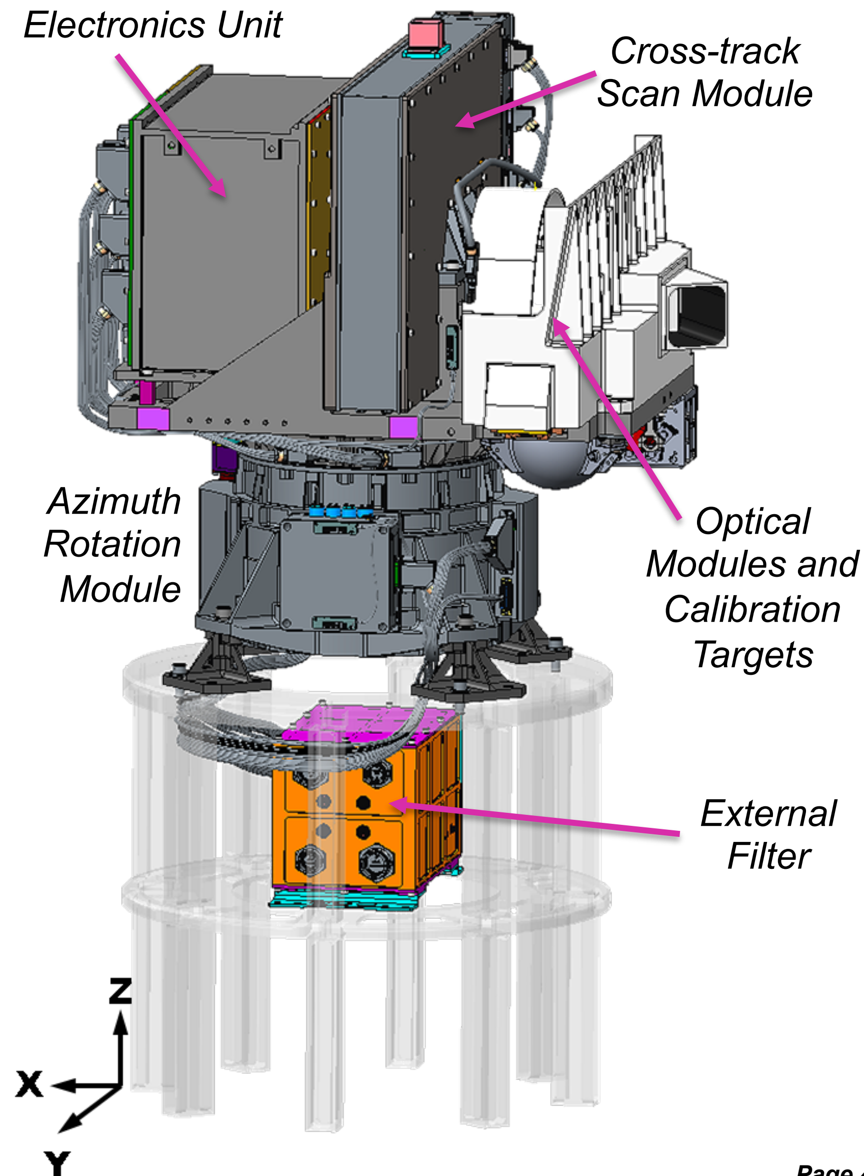


Instrument Design Addresses Mission Needs

- **Design features maximize mission performance**
  - Stable thermal environment
  - Comprehensive suite of calibration targets
  - High-performance detectors
  - Flexible operational strategy
  - PSF closely matched to CERES for best data continuity
- **Design uses flight heritage, as able, to reduce development risk**

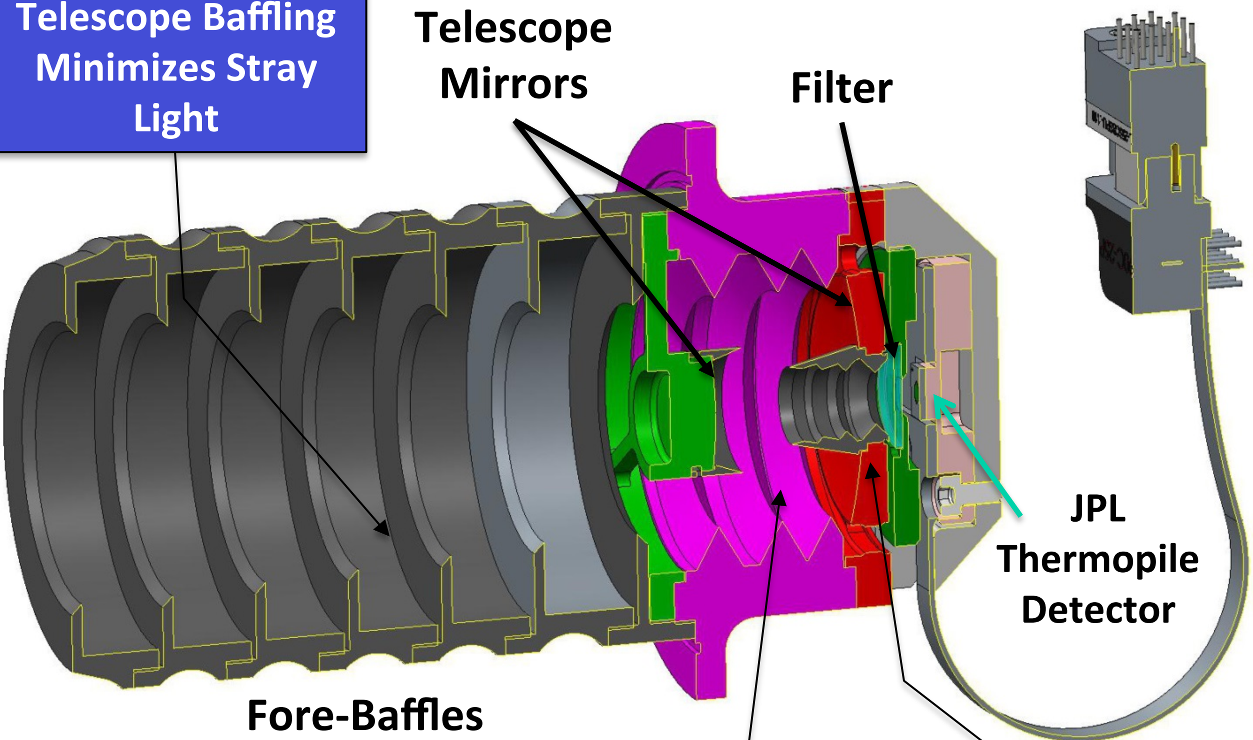
Radiation Budget Instrument is Designed to Meet Mission Needs

- **Measures upwelling earth radiance over a wide spectral range**
  - Ultraviolet to far-infrared (100um)
  - Continuous cross-track scans
- **Three spectral bands**
  - Shortwave (SW): reflected solar energy
  - Longwave (LW): emitted earth energy
  - Total: reflected solar plus emitted thermal energy
- **Very precise calibration**
  - Extensive ground calibration program establishes radiometric traceability
  - Multiple onboard targets hold calibration over mission life



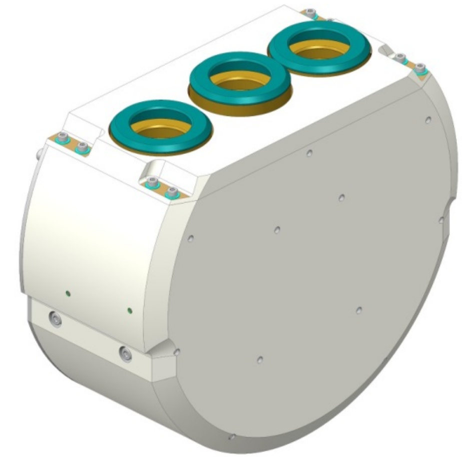
Optical Module Controls Stray Light While Providing a Stable Thermal Environment

Extensive Telescope Baffling Minimizes Stray Light



Materials Minimize Thermal Gradients

Rear Enclosure Provides Thermally Stable Environment



Optical Module

One Telescope Per Band Simplifies Detector Design

Modular Design Simplifies Integration

Radiation Budget Instrument